NASA-CR-204346

A Low Cost Realtime Telemetry Processing System

NASA-41006
NAG
7N-17-CR
027278

by

Larry A. French and Allen K. H. Huang

Teledyne Brown Engineering
Huntsville, Alabama 35807
U.S.A.

Abstract

The Pointing and Alignment Workstation (PAWS) is a low cost telemetry processing system developed by Teledyne Brown Engineering to provide realtime attitude information based on telemetry data as observed by the actual science instruments. Science payloads flown on Space Shuttle Spacelab missions frequently use the shuttle to orient the payloads at the targets of scientific interest. Although the shuttle is a good pointing platform, inevitably pointing errors stack up which result in compromises of the science data due to instrument attitude errors. PAWS was used during the first and second Atmospheric Laboratory for Applications and Science (ATLAS 1,2) shuttle missions and performed as planned by supporting realtime attitude corrections based on payload telemetry. This paper discusses the design and architecture of the PAWS low cost telemetry processing system and presents sample realtime digital and graphical displays developed to support ATLAS.

Keywords

Realtime Telemetry Decommutation Multitasking

1.0 Introduction

The Pointing and Alignment Workstation (PAWS), a telemetry acquisition and processing system, was conceived at the Marshall Space Flight Center (MSFC) primarily to support the ATLAS series of Spacelab missions. Routinely the Space Shuttle is used as a platform for pointing instruments at subjects of scientific interest. For the ATLAS series of missions the shuttle is used to orient payloads at the sun and the earth's limb to support atmospheric research. PAWS was developed to perform as a realtime mission attitude study/design tool for understanding the phenomena associated with shuttle payload pointing errors.

On the ATLAS series of Spacelab shuttle missions multiple solar and atmospheric instruments are attached to pallets mounted in the shuttle bay, and have a fixed optical axis relative to the shuttle, see Figure 1-1. This means that the instruments are totally dependent on the shuttle attitude control system to achieve the desired scientific goals. Instrument pointing errors are caused by thermal, mechanical, calibration, and attitude control system imperfections. These uncontrollable pointing error sources perturb the instrument's optical axis somewhat off the desired direction potentially resulting in a degradation of science data. PAWS observes these pointing errors and provides the information necessary to correct the error if desired.

The PAWS hardware system consists of a medium performance PC which contains all the hardware associated with acquiring, archiving, processing and distributing the telemetry stream. A complex software architecture was developed to perform the numerous tasks associated with processing the realtime spacecraft/payload data such as telemetry data decommutation, data acquisition/archiving, algorithm computations, and generating realtime displays. The PAWS realtime telemetry system was located and operated in the MSFC Spacelab Mission Operations Control (SMOC) during the ATLAS 1 and 2 Spacelab missions in the spring of 1992 and 1993.

2.0 PAWS Realtime Operations Objectives

The primary objective of PAWS is to reliably provide realtime pointing information for instruments whose line of sight was dependent on shuttle attitude. Realtime downlinked experiment data provided by the SMOC is acquired and processed by the PAWS hardware/software system. Algorithms designed by the PAWS team compute a corrected attitude which biases the baselined mission design attitude to account for the pointing error observed by the instrument. Realtime graphical displays assist the realtime mission planning cadre and the scientists to make attitude correction decisions. The video broadcasting capability permits the PAWS displays to be broadcast via a video matrix to all scientists and operations personnel within the MSFC SMOC and also to the mission planning team at Johnson Space Center (JSC) in Houston. Attitude correction information can then be relayed to the shuttle crew in order to maneuver the shuttle to null the observed pointing error.

3.0 SMOC Telemetry Format and Interfaces

The SMOC is designed to accommodate realtime scientific operations for experimenters flying Spacelab payloads. This means facilities distribute realtime data products to the experiment ground equipment as they are downlinked from the shuttle. At the SMOC, the downlink stream containing data from all the payloads is decomposed and data packets called "subsets" are constructed by the SMOC host computers. These subsets are the distributed via the SMOC telemetry network to the appropriate ground support equipment for a given experiment. Experiment data security is maintained by the definition of the contents of the subset and dedicated lines from the host computer.

SMOC Subset Definition

Figure 3-1 presents the format of a SMOC generated payload data subset. As shown by the figure, the subset is comprised of 3480 total words of two bytes (16 bits) each. A message header leads the subset and is composed of 10 words. The first three bytes

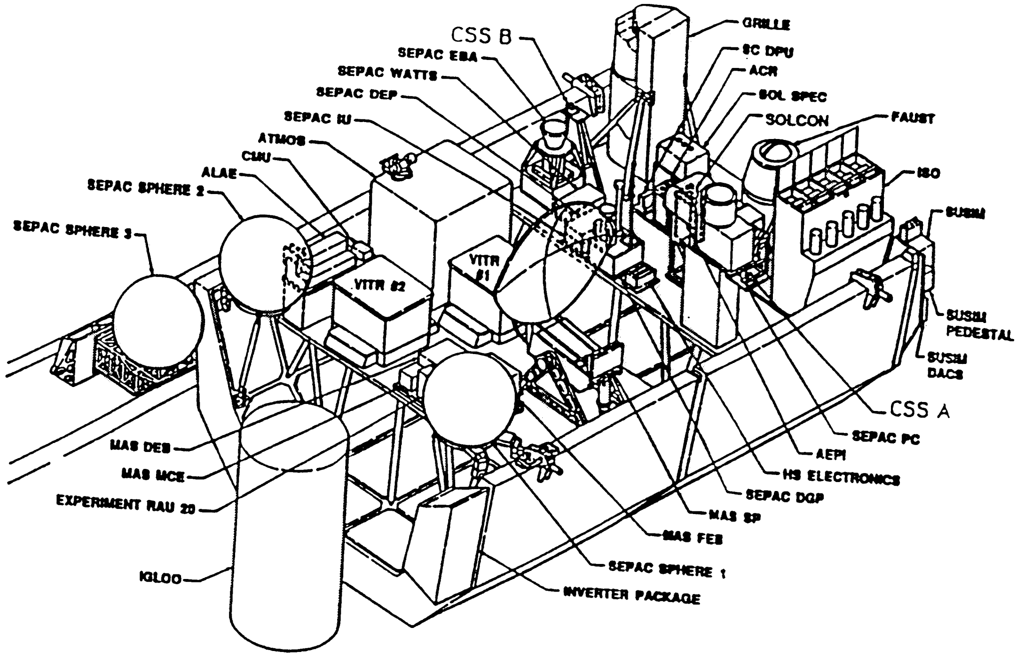

Figure 1-1 ATLAS 1 Payload Complement

of the subset are the sync pattern ("FA", "F3", "20") used by the decommutation software to identify the beginning of a new data subset. Data words 3 through 10 contain the subset time tag and maintenance data. Finally words 11 through 3480 contains the actual downlinked realtime science or payload data desired. The data is sent asynchronous at a baud rate, predetermined by the user, of either 2400, 4800, 9600, 19200, 38400, or 76800. Subsets are sent at a frequency of one per second.

BYTE	MSB	LSB	BYTE
1	Sync (Hex "FA")	Sync (Hex "F3")	2
3	Sync (Hex "20")	Spare	4
5	ECR ID	DQM	6
7	Time	Time	8
9	Time	Time	10
11	Time	Time	12
13	Message Length	Message Length	14
15	Frame Counter	Frame Counter	16
17	Spare	Spare	18
19	Spare	Spare	20
21	Data Word 1		22
23	Data Word 2		24
25	Data Word 3		26
27	Data Word 4		28
Last Byte	Data Word n		Last Byte

Figure 3-1 SMOC Data Subset Format

Subset Physical Interface

The asynchronous subset utilizes the EIA RS-530 specification, which provides a RS-422 electrical interface through a standard DB-25 (25 pin) female connector. This common interface permits the use of common, low cost, PC based asynchronous communications hardware. The RS-422 interface significantly simplifies the whole realtime data processing architecture.

4.0 PAWS Architecture Overview

The PAWS telemetry acquisition/processing system was designed using low cost PC based hardware and software. Minimum cost dictated minimum risk therefore the system was designed utilizing existing telemetry decommutation software and off-the-shelf communications hardware. In contrast to the majority of experimenters processing Spacelab payload data, PAWS did not use any custom hardware for any of the telemetry processing. The following sections discuss the hardware and software architecture.

Hardware Architecture

At the time of the computer hardware purchase, the 486 based PC's were new to the market. Therefore, due to concerns of hardware reliability in a critical application proven 386 based equipment was selected. The system was used successfully on two missions (ATLAS 1 and 2) for processing complicated, math intensive data processing algorithms in addition to the decommutation/archiving tasks of the computer. This was performed on a generic 386-33Mhz PC with a 150 Meg ESDI drive. The computer was equipped with a math coprocessor to speed math operations. The ESDI technology was selected as the best option at the time to increase the I/O data rate to mass storage. During the development, testing and realtime operations the system was computationally stressed to determine if the computer was approaching the limits of its throughput. It is estimated that the 386 system had a reserve of approximately 30% processing time after completing the communications and computational tasks. The system has recently been upgraded to a 486-50 Mhz capability to satisfy growing processing needs.

As discussed earlier a standard RS-422 interface is available in the SMOC and permitted the use of a readily available off-the-shelf plug-in asynchronous communications board for the PC. The card will handle a data rate of one Mbps which is more than adequate for the standard SMOC data rate of 32 Kbps. Software provided by the communications board manufacturer, Sealevel Systems Inc., was included in the decommutation software for initialization of the board. The communications board has worked with 100% reliability during all PAWS operations.

The PAWS realtime PC is connected to another PC and a Macintosh via an ethernet which permits off-line processing during periods of loss-of-signal (LOS) or payload inactivity. Transferring archived data from the realtime machine quickly via the ethernet allows near realtime analysis of phenomena observed during the data receiving period. The ethernet connection to the "off-line" machines provides flexibility in performing numerous special studies requested by the mission scientists.

Software Architecture

Figure 4-1 presents an overview of the PAWS software architecture. As shown by the figure, the system runs in a multitasking mode on the PC. The telemetry decommutation, raw data archiving and communications card interface is performed using a customized version of a software package called PCDecom. This communications software runs in one multitasking session (called a virtual machine) while the attitude analysis/display software is running in another session. The analysis software is receiving realtime parameters through expanded memory and performing the attitude related computations necessary to update the digital and graphics screens. This architecture reliably executes all the realtime computations, realtime display updates, data archiving and communications tasks on the previously described PC.

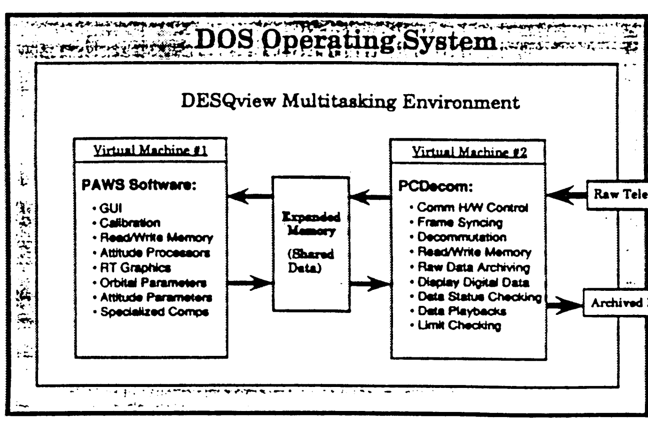

Figure 4-1 Software Architecture Overview

Decommutation Software Discussion

The commercial software package PCDecom was selected for performing the telemetry stream decommutation, digital data display, and raw data archiving. PCDecom was selected after an extensive review of available systems on the market. Historically the decommutation process has been resolved using expensive hardware solutions. The advent of powerful, low cost PC's has permitted the development of a solution to this difficult problem which is primarily software. Use of PCDecom permitted maximum flexibility in defining the telemetry stream, data characteristics, and the data display formats.

The decommutation software is responsible for handling all of the communications hardware control tasks including initializing the card, moving data from the card to the appropriate memory location, and monitoring for the subset sync words. Configuring the decommutation software for the specific application is performed by building databases using supplied utilities. Databases are constructed which define the telemetry stream, in this case the SMOC supplied subset. One database defines the exact location and length of all the data parameters in the subset. Each parameter is assigned a variable name by the user which serves as the identifier for the variable in the data display screens. This database also describes the length of this parameter (1, 2, 4, or 8 bytes) and the data type, whether integer, real, or double precision.

Once the databases are constructed defining the input telemetry stream, the construction of the data display screens can commence. A screen builder utility provided with PCDecom permits the user to interactively develop data screens for the realtime parameters of interest. These screens display the actual values of the parameters as downlinked. The screen builder permits the assigning of limit checking to the parameters so flags may be triggered if a value is out of limits. Figure 4-2 presents a typical digital data screen build using the PCDecom utilities.

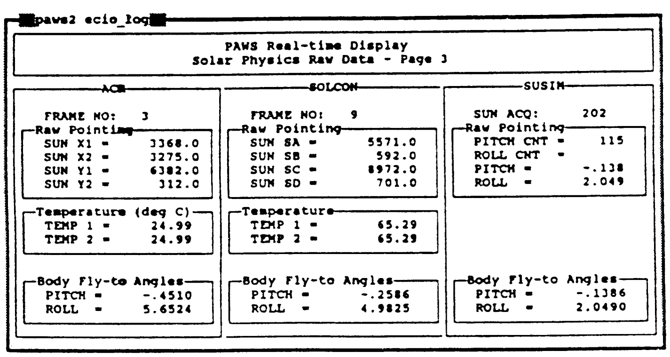

Figure 4-2 Generic PCDecom Realtime Display

An additional expanded memory interface feature was added to PCDecom to accommodate the needs of the PAWS developers. The expanded memory interface permitted the PAWS developed algorithms, special utilities, and graphics displays to use the realtime values as they were acquired by the the decommutation software.

Analysis and Graphical Display Software

Since the PCDecom software package is supplied as an executable, the user is unable to make modifications to this code.

For the PAWS application, this was an unacceptable situation which caused the development of the expanded memory interface for data being shared by the two applications. As shown by the overall system architecture of Figure 4-1, a DESQview multitasking environment was implemented which permitted the simultaneous execution of the decommutation software with the realtime data analysis software developed by the PAWS team.

A graphical user interface (GUI) was written to provide program control for the graphics displays and for the selection of the algorithms to be processed. This simple GUI employed pull down windows which contained the options available for the operator. This GUI permitted the realtime operations to be manned by personnel who were not thoroughly familiar with the software.

The PAWS analysis software running in the first DOS session under DESQview is continuously polling the data in the shared expanded memory. The PCDecom software places the new realtime parameters which have been decommutated into the shared memory. When the PAWS analysis software determines that new values are loaded, these values are then processed via the attitude processing routines and graphed using the realtime graphics routines. Since PCDecom is used by the PAWS system to display the digital data, processed values from the analysis code are passed back to the second DOS session for display by PCDecom.

5.0 Example Solar Science Realtime Displays

In order to process the raw experiment data from the solar instruments, calibration coefficients and data stream formats were acquired from the experiment teams. Using experimenter of the payloads processed by PAWS supplied calibration equations and constants for each instrument to compute the pointing error of the observed sun relative to the instrument. The instrument pointing error is computed in terms of a roll and pitch error relative to the instrument's optical axis. These roll and pitch values define a pointing axis to the desired science axis (center of the sun). The PAWS solar attitude processor algorithms use the roll and pitch values in addition to yaw information extracted from the IMU based attitude quaternion to build a complete inertial frame of the instrument.

The outputs from the attitude processors and the calibrated raw data is displayed realtime by the computer in both digital and graphical trend form. Figure 5-1 presents a sample digital solar data screen. This screen presents processed values from the instrument in addition to values computed by the special attitude determination algorithms.

Figure 5-2 presents a sample solar realtime graphical plots which can be updated simultaneously with the digital display. This figure illustrates scatter plot data of all the instruments being processed. The plot serves as a strong visual tool to determine attitude corrections which may be accomplished without severely degrading the pointing of the other instruments. The ability to collectively process and display pointing information of all the instruments simultaneously is the essence of the PAWS mission.

6.0 PAWS Telemetry System Conclusions

The PAWS telemetry processing system proved that specialized, high cost telemetry decommutation hardware is no longer a necessary expense to reliably handle spacecraft/experiment downlink telemetry data. The current capabilities of high performance PC's are adequate for data rates from .5 to 2 Megabits per second. Processing speeds available with the current generation of 486 based PC's provides considerable capability for performing complex mathematical operations and updates of sophisticated displays in realtime.

The PAWS system described in this paper has also been conceptualized as the basis for a distributed processing network. In this scheme the main decommutation PC would also function as a server distributing data packets to other PC's on an Ethernet. This configuration has been successfully executed using the PCDecom software for the shuttle Tethered Satellite Program. By adding the network an increased level of participation by other payload team members is possible by including more workstations. This permits not only the distribution of the computation responsibilities but also division of team member tasks.

The PAWS telemetry processing system has proven to be a cost efficient, reliable, and operationally powerful tool for performing telemetry related problems. Telemetry acquisition/decommutation in the recent past consisted of expensive semi-custom hardware. This is being replaced by commercially available, high performance PC's with proven reliability. The

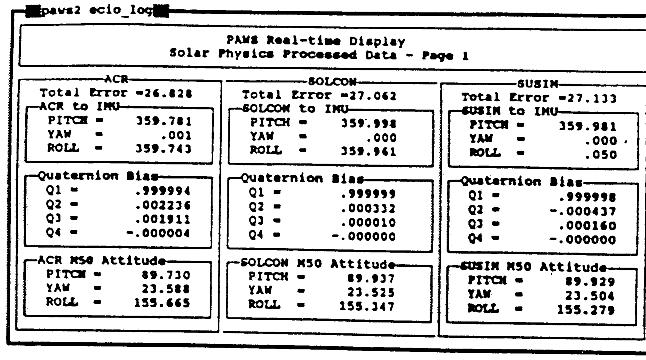

Figure 5-1 Sample Realtime Solar Digital Display

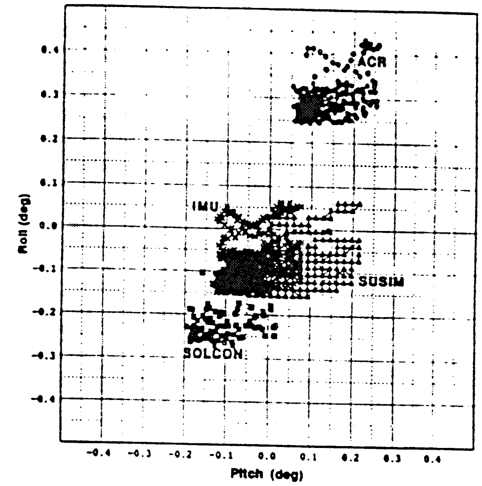

Figure 5-2 Sample Realtime Graphical Plots

success of PAWS demonstrates a capable system sized and priced to support telemetry dependent operations from microsat data processing to sophisticated Spacelab payload support.

References

[1] FRENCH, L.A., HUANG, K.H., TRAUFLER, P.E., *Pointing and Alignment Workstation (PAWS) Final Report*, MSFC PMIC Doc. No. 410RPT0146, Sept. 1992.

[2] "Marshall Space Flight Center POCC Telemetry and Command Data Base Definition", MSFC-DOC-1149A, April 1990.

[3] "Mission Configuration Document, ATLAS 2", MSFC-HOSC/MCD3200.056, Sept 1992.

[4] HUANG, K.H., FRENCH, L.A., "Attitude Determination by Using Horizon Sensors and Sun Sensors", Paper presented at the First Pacific International Conference on Aerospace Science and Technology, Dec 6-9, 1993.

[5] WERTZ, J.R., *Spacecraft Attitude Determination and Control*, Boston, Kluwer Academic Publishers, 1978.

SM

NASA SCIENTIFIC AND TECHNICAL DOCUMENT AVAILABILITY AUTHORIZATION (DAA)

To be initiated by the responsible NASA Project Officer, Technical Monitor, or other appropriate NASA official for all presentations, reports, papers, and proceedings that contain scientific and technical information. Explanations are on the back of this form and are presented in greater detail in NHB 2200.2, "NASA Scientific and Technical Information Handbook."

☐ Original
☐ Modified

(CASI Use Only)
Control No. ______
Date ______

I. DOCUMENT/PROJECT IDENTIFICATION (Information contained on report documentation page should not be repeated except title, date and contract number)

Title: A Low Cost Realtime Telemetry Processing System

Author(s): Larry A. French and Allen K. H. Huang

Originating NASA Organization: MSFC

Performing Organization (if different): Teledyne Brown Engineering

Contract/Grant/Interagency/Project Number(s): NAS8-41000

Document Number(s) ______ Document Date: ______

(For presentations or externally published documents, enter appropriate information on the intended publication such as name, place, and date of conference, periodical or journal title, or book title and publisher: Pacific Inter. Conf. on Aerospace Sci. & Tech. Tainan, Taiwan, Republic of China, December 6-8, 1993

These documents must be routed to NASA Headquarters, International Affairs Division for approval. (See Section VII))

II. AVAILABILITY CATEGORY

Check the appropriate category(ies):

Security Classification: ☐ Secret ☐ Secret RD ☐ Confidential ☐ Confidential RD ☑ Unclassified

Export Controlled Document - Documents marked in this block must be routed to NASA Headquarters International Affairs Division for approval.

☐ ITAR ☐ EAR

NASA Restricted Distribution Document

☐ FEDD ☐ Limited Distribution ☐ Special Conditions-See Section III

Document disclosing an invention

☐ Documents marked in this block must be withheld from release until six months have elapsed after submission of this form, unless a different release date is established by the appropriate counsel. (See Section IX).

Publicly Available Document

☑ Publicly available documents must be unclassified and may not be export-controlled or restricted distribution documents.

☐ Copyrighted ☐ Not copyrighted

Conc: JA01/Harry G. Craft, Jr. Jack R Bean

III. SPECIAL CONDITIONS

Check one or more of the applicable boxes in each of (a) and (b) as the basis for special restricted distribution if the "Special Conditions" box under NASA Restricted Distribution Document in Section II is checked. Guidelines are provided on reverse side of form.

a. This document contains:

☐ Foreign government information ☐ Commercial product test or evaluation results ☐ Preliminary information ☐ Information subject to special contract provision

☐ Other—Specify ______

b. Check one of the following limitations as appropriate:

☐ U.S. Government agencies and U.S. Government agency contractors only ☐ NASA contractors and U.S. Government agencies only ☐ U.S. Government agencies only

☐ NASA personnel and NASA contractors only ☐ NASA personnel only ☐ Available only with approval of issuing office; ______

IV. BLANKET RELEASE (OPTIONAL)

All documents issued under the following contract/grant/project number ______ may be processed as checked in Sections II and III.

The blanket release authorization granted ______ (Date) is:

☐ Rescinded - Future documents must have individual availability authorizations.

☐ Modified - Limitations for all documents processed in the STI system under the blanket release should be changed to conform to blocks as checked in Section II.

V. PROJECT OFFICER/TECHNICAL MONITOR

Typed Name of Project Officer/Technical Monitor	Office Code	Signature	Date
Robert E. Lake	JA21	Robert E. Lake	Oct. 12, 1993

VI. PROGRAM OFFICE REVIEW ☒ Approved ☐ Not Approved

Typed Name of Program Office Representative	Program Office and Code	Signature	Date
~~Robert Rhome~~ Lisa Shaffer		Lisa Shaffer	10/26/93

VII. INTERNATIONAL AFFAIRS DIVISION REVIEW

☐ Open, domestic conference presentation approved.
☐ Foreign publication/presentation approved.
☐ Export controlled limitation is approved.
☐ Export controlled limitation is not applicable.
☐ The following Export controlled limitation (ITAR/EAR) is assigned to this document: ______

International Affairs Div. Representative	Title	Date
[illegible signature]	Personnel Exchange Officer	10/29/93

VIII. EXPIRATION OF REVIEW TIME

The document is being released in accordance with the availability category and limitation checked in Section II since no objection was received from the Program Office within 20 days of submission, as specified by NHB 2200.2, and approval by the International Affairs Division is not required.

Name & Title ______ Office Code ______ Date ______

Note: This release procedure cannot be used with documents designated as Export Controlled Documents, conference presentations or foreign publications.

IX. DOCUMENTS DISCLOSING AN INVENTION

a. This document may be released on ______ (Date) Installation Patent or Intellectual Property Counsel ______ Date ______

b. The document was processed on ______ (Date) in accordance with Sections II and III as applicable. NASA CASI ______ Date ______